ARM PROGRESS REPORT

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Title of Research Grant: A continuation of modeling and analysis activities in support of the goals of the Atmospheric Radiation Measurement (ARM) program.

Scientific Goals of Research Grant: Our current focus is on investigating the fundamental nature of cloud and radiation processes in the tropical western Pacific with the goal of improved treatment of these processes in general circulation models. Our observational studies are currently concentrating on an improved understanding of the diurnal cycle of clouds and precipitation, on the behavior of shallow clouds during suppressed conditions and on the degree to which the Atmospheric Radiation and Cloud Station (ARCs) at Nauru is contaminated with island effects. Hypotheses generated from the observations are being tested using cumulus ensemble models (CEMs) and SCMs with shortcomings in cloud parameterizations already noted.

Highlights of Accomplishments:

- There is still considerable debate on what processes cause the diurnal cycle of clouds and precipitation over tropical oceans. Our work shows that the diurnal cycle of rainfall may be driven by diurnal variations in atmospheric stability even over tropical oceans.
- The errors in humidity measurements taken by Vaisala rawinsondes were investigated. The impact of correcting calibration problems in the upper troposphere and humidity biases throughout the troposphere were found to be larger than changes induced by many assessments of greenhouse warming. Another study that began using the NAURU99 data recommends that ground check data for operational rawinsonde measurements be archived but not used in real-time as several examples errors in the operational data stream have been detected.
- A cumulus ensemble model was able to replicate the observed behavior of shallow clouds during a very dry suppressed period over the tropical western Pacific. Initial tests of the cloud parameterization schemes used in the NCAR Community Climate Model were unable to replicate this behavior prompting further investigations.
- Using data from the NAURU99 experiment taken aboard the R/V Mirai we found only modest contamination from island effects on the NAURU ARCs measurements. The physical model for these effects is a heat island driven by an enhanced sensible heat flux.
- Using data from a Water Vapor (IOP) Intensive Observing Period in the vicinity of ARM's Southern Great Plains site, we were able to successfully undertake one of the first mesoscale tests of a four-dimensional variational data assimilation system. Mesoscale simulations were also used to detect short-comings in commonly utilized cloud and radiation parameterizations.

Summary of Progress and accomplishments during last twelve months:

Diurnal cycle of cloud and precipitation over the tropical Pacific: The diurnal cycle of clouds and precipitation is of most fundamental importance to weather given that the timing of so many human activities is determined by the diurnal cycle. The diurnal cycle of clouds and precipitation is also important to climate predictions since an inaccurate treatment of the diurnal cycle degrades climate prediction. This behavior is not surprising if one notes the importance of cloud-radiative interactions to climate predictions and that the timing of clouds within the diurnal cycle determines to a large degree the nature of this interaction. What is surprising is that there is not yet a consensus on what process(es) control the diurnal cycle of clouds and precipitation over tropical oceans, despite vastly improved data sets and the recent application of more advanced modeling strategies. Over middle latitude continents, the diurnal cycle of clouds and precipitation is often discussed within the context of processes that modulate atmospheric stability (e.g., solar insolation directly and indirectly heating the atmospheric boundary layer) or low-level convergence (e.g., differential heating/cooling driving land-sea breezes or mountain valley circulations). In contrast, many investigations of the diurnal cycle over tropical oceans have elected to begin with the implicit assumption that this framework is largely irrelevant to the diurnal cycle of clouds and radiation over tropical oceans. These investigators have instead proposed, for example, that the diurnal cycle of clouds and precipitation over tropical oceans is driven by such processes as direct cloud-radiative interactions, compensating subsidence/ascent between clear and cloudy regions and/or diurnal variations of water vapor.

Utilizing data taken during ARM specially sponsored cruises for the NAURU99 and TOCS (Tropical Ocean Climate Study) experiments, we have examined whether changes in atmospheric stability might be able to explain the diurnal cycle of rainfall over tropical oceans. The data sets were taken aboard the JAMSTEC (Japan Marine Science and Technology Center) research vessels and included well calibrated rawinsonde soundings launched at 3-hr intervals and a variety of in-situ and remote sensing measurements. Our findings include: a) the detection of clear diurnal signals in atmospheric stability during suppressed periods when the local impacts of convection are minimized; b) the observation that these signals vary with convective regime (deep convection has a single pre-dawn maximum, while light winds have both evening and pre-dawn maximum); c) that scaling argues indicate that these stability changes might explain a significant portion of the diurnal cycle of rainfall; and d) that these diurnal variations in stability are in turn driven by the interplay of several processes each with its own diurnal cycle. These processes with their own diurnal cycles include surface fluxes, clear-air radiative transfers, clear-air vertical motions and the general evolution of the boundary and the shallow cumulus non-precipitating cumulus. The initial results are discussed in Parsons[1] et al. (2000) with an article to be submitted to the *J. Atmos. Sci*. within the next several months. The results of this study and that of Parsons[2] et al. (2000) clearly indicate the importance of the interplay of short-wave absorption and long-wave cooling in impacting the creation of convective instability and how this interplay depends on the vertical profile of water vapor.

[1] See list of non-reviewed articles.
[2] See list of reviewed articles.

Humidity measurements from rawinsondes: Accurate measurements of humidity are necessary for the goals of the ARM project as radiative transfers are so dependent on the vertical profile of water vapor. Guichard[2] et al. (2000) discusses the magnitude, correction and meteorological impact of three common sources of errors for Vaisala rawinsondes. The first error is the so-called "dry bias". This error arises as contamination of the sensor occurs from out gassing from materials stored inside the sonde packaging. The error is relatively uniform over the depth of the troposphere and is typically ~3-5% in relative humidity. This error can be corrected using the age of the sonde or a reference measurement, such as an accurate surface point or as is done in ARM a measure of the integrated water vapor from radiometers. The ad-hoc scaling procedure developed by ARM should work fairly well for this error as it is relatively constant with height to first order through the troposphere. A second source of error is sensor arm heating, which if present can be corrected utilizing accurate surface data, a model of the error characteristics and knowledge of the dry bias. The third source of error, which can be larger than the dry bias effect aloft, occurs due to calibration inaccuracies for conditions in the upper-troposphere. Vaisala has re-examined their calibration procedures resulting in a reduction in the magnitude of this error. Guichard et al. (2000) show how these errors have an impact on the radiation budget that is large relative to estimates of the green house effect making correction of these errors an important matter.

NAURU99: NCAR participated in the NAURU99 campaign by providing and/or maintaining several instruments on the JAMSTEC R/V Mirai. D. Parsons at NCAR is also co-investigator for JAMSTEC to conduct atmospheric studies on the Mirai over the tropical western Pacific. The instrumentation provided by NCAR included wind and spaced antenna profilers, a dual-channel microwave radiometer, sea surface measurements with a sea snake and surface meteorological measurements (Brown[1] et al. 2000a). Several studies have arisen from this participation, in addition to the diurnal cycle study discussed previously. The first study is an investigation by Wang[1] et al. (2000) of the accuracy of humidity measurements taken by the rawinsondes from the R/V Mirai. According to the Wang study, the humidity measurements did not suffer from dry bias results so that the measurements should not require any post-calibration procedures or ground checks. The lack of a dry bias problem meant that the ground check actually contributed significant errors to the measurements so that any studies utilizing the JAMSTEC data should use the data that was reprocessed to remove the ground check. The study also makes the bold recommendation that in operational settings the ground check data is archived but not used in real-time as several examples of errors induced in the operational data stream are presented.

Another investigation based on the NAURU99 data set is Brown[1] et al. (2000b) where evidence is presented for Nauru generating a heat island. The net effect of this heat island is a warmer and slightly drier and deeper boundary layer. The magnitude of the warming can be used to estimate surface sensible heat fluxes for the island, which were found to be nearly two orders larger than over the open ocean. The distribution of long wave radiation received at the surface is impacted both by these drier conditions and the presence of more vigorous shallow clouds. Lower pressure and disturbed winds were also observed suggesting a possible blockage effect of the island, although we are also investigating whether this effect is due to errors from the ship's velocity. The effects that were documented in this study were found from data taken as the R/V Mirai moving in and out of the lee of the island so that the effects are thought to represent an integral upper-bound to the island effects experienced at the Nauru ARCS. An additional study is underway using the continuous vertical motion measurements obtained with NCAR's spaced antenna wind profiler to show that convective systems in the tropics sometimes modify their local environment through internal waves to make the environment more favorable to deep convection. This study has implications for the way in which precipitation systems in the tropics are parameterized as do the studies discussed in the next subsection.

Parameterization of clouds over the tropical western Pacific: Parsons[2] et al. (2000) discuss how shallow cumulus and cumulus congestus clouds remoisten the tropical atmosphere following the intrusion of dry air from higher latitudes. The moistening process for the lower and middle troposphere takes ~10-20 days. Redelsperger[1] et al. (2000) discussed how the general character of the cloud field observed during the recovery was well represented by simulations with a cloud-resolving model, while preliminary tests with the Single Column Model of the NCAR failed to replicate this observed pattern. Investigations are underway during this summer, while Redelsperger is a visitor at NCAR, to try to explain and/or improve the behavior of the climate modeling system.

In another study of the parameterization of clouds over the tropical western Pacific, Guichard[1] et al. (2000) tested several convective parameterization schemes during a ten-day simulation using a mesoscale model. The schemes utilized were Grell, Kain-Fritsch and Betts-Miller. Guichard et al. (2000) found that the schemes produce reasonable agreement with observations in terms of the water cycle and the mean distributions of precipitation. The various schemes did produce significant differences in the cloud cover and the organization of the simulated convection. The differences in the cloud field impact the thermodynamics of the atmosphere through cloud-radiative interactions. Additional simulations are being conducted to access the performance of these parameterizations in terms of the cloud fields and cloud-radiative interactions.

Boundary conditions for Single Column Models: Guo[2] et al. (2000) utilized data from an ARM Water Vapor IOP in a test of a four-dimensional data assimilation system. The assimilation system was able to reproduce the observed rainfall pattern and amount and substantially reduced the model errors. The high spatial and temporal resolution of the system is unique. This high temporal resolution is well suited for the remote sensors available to ARM over the southern Great Plains, while the use of multiple times potentially affords increased accuracy of static data assimilation and objective analysis techniques. The potential accuracy of this approach is evident by interest of the operational centers in utilizing three and four-dimensional assimilation to initialize forecast model, while objective analysis are generally relegated to error checks rather than model initializations.

Publications-refereed:

Guichard, F., D. B. Parsons, and E. Miller, 2000: Thermodynamic and radiative impact of the correction of sounding humidity bias in the Tropics. In press: *J. of Climate*.

Guo, Y.-R., Y.-H. Kuo, J. Dudhia, D. Parsons, and C. Rocken, 2000: Four-dimensional variational data assimilation of heterogeneous mesoscale observations for a strong convective case. *Mon. Wea. Rev*., **128**, 619-643.

Parsons, D. B., K. Yoneyama, and J.-L. Redelsperger, 2000: The evolution of the tropical western Pacific atmosphere-ocean system following the arrival of a dry intrusion. *Quart. J. Roy. Meteor. Soc*., **126**, 517-548.

Publications-non-refereed:

Brown, W.O.J., D. B. Parsons, E. R. Miller, S. A. Cohn, and K. Yoneyama, 2000: Profiler, radiometer, SST and meteorological observations from the R/V Mirai during Nauru99. *Proceedings of the Tenth Atmospheric Radiation Measurement Science Team Meeting*, San Antonio, Texas, in press.

Brown, W.O.J., D. B. Parsons, and S. A. Cohn, 2000: NAURU99: Profilers cruise the central Pacific. Preprints: Preprints: short abstracts submitted to the 9th International Workshop on Technical and Scientific Aspects of MST radar- combined with COST-76 Final Profiler Workshop. Toulouse France. 8.5.

Guichard, F., J. Dudhia, and D. Parsons, 2000: COARE simulations with the mesoscale model MM5: Various sensitivities to physical parameterizations. Preprints 24th Conf. on Hurricanes and Tropical Meteorology. Ft. Lauderdale, FL, 514-515.

Parsons, D. B., F. Guichard, E. Miller, S. Cohn, W.O.J. Brown, and K. Yoneyama, 2000: A new look at an old problem: The diurnal cycle of rainfall over tropical oceans. Preprints 10th Conf. on Interaction of the Sea and the Atmosphere. Ft. Lauderdale, FL, 14-15.

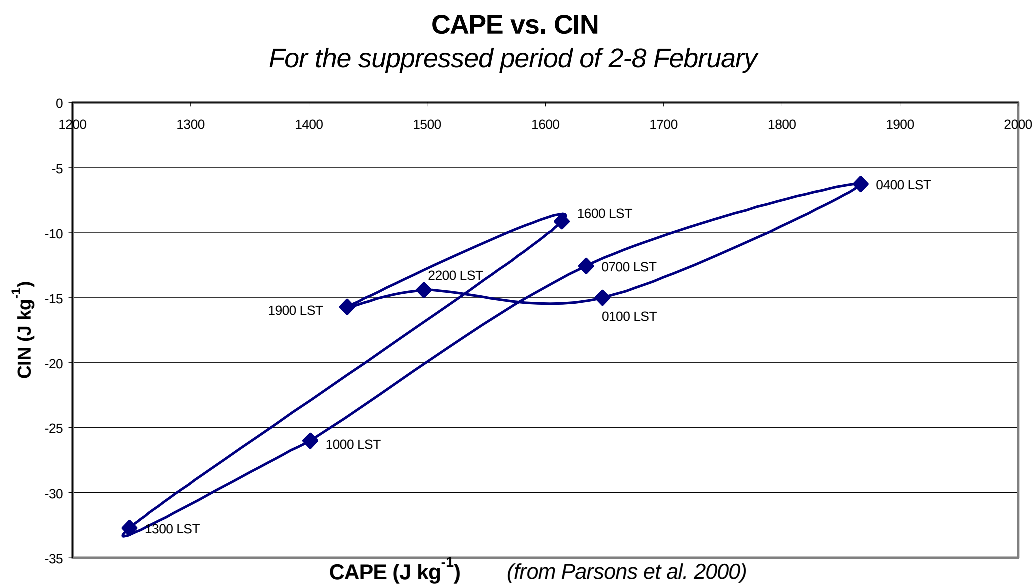
Redelsperger, J.-L., D. Parsons, and F. Guichard, 2000: Preprints 24th Conf. on Hurricanes and Tropical Meteorology. Ft. Lauderdale, FL, 514-515.

Wang, J., W. Brown, D. J. Carlson, H. L. Cole, E. R. Miller, D. B. Parsons, and K. Yoneyama, 2000: Ground-check corrections in radiosonde data on the R/V Mirai during NAURU99. *Proceedings of the Tenth Atmospheric Radiation Measurement Science Team Meeting*, San Antonio, Texas, in press.

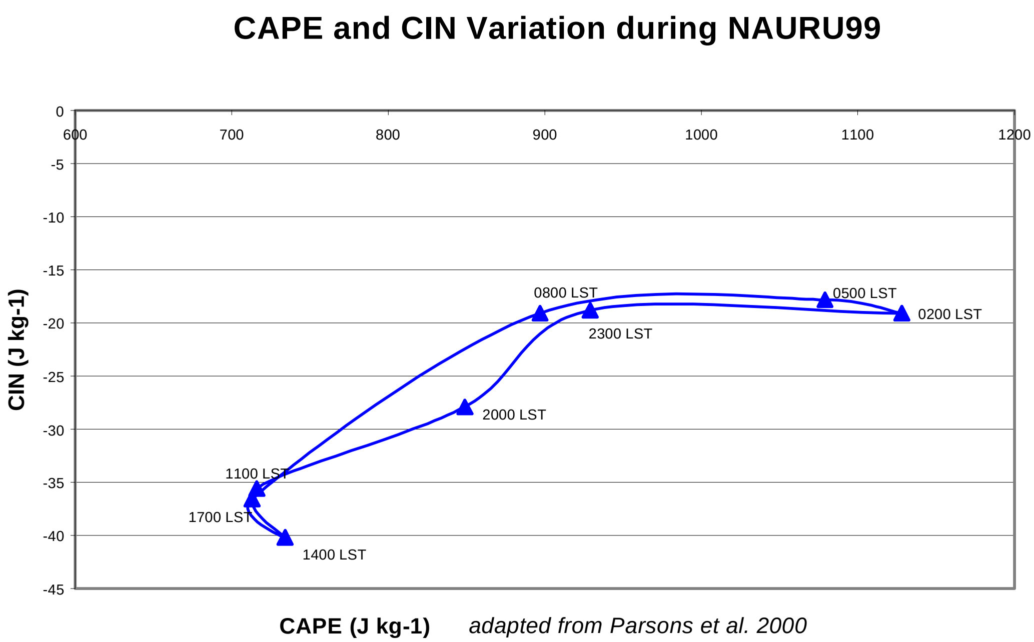
Prior submitted refereed publications now appear in current list.

Exactly what mechanisms are responsible for the diurnal cycle of rainfall over the tropics is still a subject of active debate despite decades of active research. Using ARM data taken on special cruises over the tropical western Pacific on Japanese research vessels, Parsons et al. (2000) has proposed that the diurnal cycle of rainfall over tropical oceans is driven by changes in the stability of the tropical atmosphere to convective processes. The stability variations are driven, in turn, by the interplay of several diurnal processes (surface fluxes, large-scale vertical motions, clear air radiative transfers and changes in boundary layer character). Previous studies have often concentrated on explaining the diurnal cycle of rainfall with processes that are not dependent on the atmospheric stability, such as day-night differences in the direct interaction between clouds and the radiation. Two examples of stability changes from the Parsons et al. (2000) study are shown. The measures of stability plotted are the CAPE (convective available potential energy—a measure of convective intensity) and CIN (convective inhibition—a measure of the ease at which convection is initiated). These two examples represent different types of diurnal cycles. In the first example, representative of light wind conditions over the western Pacific, there are typically rainfall peaks in the evening and pre-dawn hours which also correspond to two periods with favorable stability parameters. The second example is in higher wind speeds during the NAURU99 project. Such a regime typically has only a pre-dawn maximum in rainfall again corresponding to a peak in the stability parameters.

Below is a graph of the stability variations in light winds over the TWP where two peaks in rainfall are expected.



Below is a graph of the stability variations in stronger winds during NAURU99 where a single peak in rainfall is expected.



adapted from Parsons et al. 2000